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Informing energy justice based decision-making framework for waste-to-energy technologies selection in sustainable waste management: A case of Iran

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ABSTRACT

Due to problems such as limited land area for waste disposal and waste-borne diseases, waste management organizations have increasingly been offering technologies for recovering energy from waste. These technologies can help governments, local authorities, developers and investors for mitigating climate change and building sustainable societies. The suitable waste-to-energy production technology selection is a complex issue in waste supply chain management that must not only be assessed in terms of both socioeconomic and environmental criteria. With the purpose of balance between energy trilemma issues in the context of waste-to-energy generation and develop sustainable waste management strategies in the waste chain, energy justice criteria must also be taken into consideration. The paper considers the application of an integrated multi-criteria decision-making model consisting of fuzzy decision-making trail and evaluation laboratory method, the analytic network process and the simple additive weighting approaches. The integrated method can be applied to select the suitable technology in a sustainable manner, taking into account energy justice criteria. The applicability of proposed model is demonstrated by a case study of the technology selection in the city of Behbahan, Iran. It includes various technologies for waste-to-energy generation and ranks technologies from the most to least preferred as: Anaerobic digestion, Gasification, Pyrolysis, and Incineration.

1. Introduction

Energy systems have changed the face of the world and have a decisive role in human life, both individually and socially. The use of fossil fuel-based energy resources, by providing electricity, heat and easy transportation, has facilitated the life. Nevertheless it had devastating effects on the world, such as global warming and rising seas level, air pollution, desertification, forced migration and concerns about human happiness, welfare, freedom, and equity (Jones et al., 2015). Improper use of energy by creating problems like pollution and global warming on the one hand, and energy poverty and under-consumption on the other, play a catalytic role for many social and environmental problems (Wilkinson et al., 2007). The conditions of the world show that the sphere of influence of energy systems is not limited to economic and technological development, but covers deeper social, political, cultural, and moral issues (Sovacool et al., 2017).

Most energy-related decisions and actions have only been taken to improve engineering performance and economic efficiency. Handling the interactions between the widespread effects of energy systems on environmental and social changes requires more attention to human needs and desires in decision-makings and actions. In new perspectives, energy systems are not merely simply hardware and devices for providing power, fuel, electricity and so forth. Energy systems are defined as socio-technical systems because their physical infrastructures and technologies are interlocked with user life styles, practice and organizations (Kern and Smith, 2008; Markard et al., 2012). In this new comprehensive form of energy systems definition, there are serious challenges for management and planning. World is witnessing an increase in

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energy demand due to population growth and economic developments. Energy consumption is envisaged to increment by 25–34% in the next 20 y (BP, 2017). Countries need to respond to this increased demand for energy by securing diverse and sufficient energy resources. Climate change caused by greenhouse gas emissions threatens human life. It is necessary to move toward long-term sustainable energy supply and low-carbon emission. According to statistics and reports, an impressive contribution to global energy demand is provided by fossil fuels. This impressive contribution will not be significantly reduced in the near future. Based on the reports, by the year 2035, about 80% of the energy needs are from non-clean fuels (IEA, 2016; "Statistical Review of World Energy | Energy economics | BP," n.d.). Energy is one of the essential requirements of human life. Decisions and measures to secure energy resources and reduce carbon emissions should not endanger the ability of individuals to access energy (financially and so on).

The above-mentioned challenges and many others in the field of energy systems can be addressed under three headings: Climate Change, Energy Poverty and Energy Security, which are known as energy trilemma (McCauley, 2017). It is clear that the objectives of each part of the system are contradictory with other parts, and if planning for each part, taking into account the needs and desires of the same part, it is impossible to reach a solution for concerns that mentioned above. There is a need to make planning with consideration of different parts of the system such as production, distribution, and consumption as a unified system with the purpose of solving the concerns in the energy trilemma. It seems that selected frameworks and criteria such as socioeconomic and environmental criteria for decision-making and management in these systems are not properly equipped. These frameworks cannot handle the complex relationships of energy problems and reach a balance between conflict demands of the climate change, energy poverty and energy security (Markowitz and Shariff, 2012). Energy justice is one of the most notable concepts in recent years that has appeared in research across many domains (Heffron and McCauley, 2017). Energy justice uses moral and social concepts for making impartial decisions in energy production, distribution, and consumption and helps to the equitable dissemination of the costs and benefits of energy systems (Sovacool, 2013; Sovacool and Dworkin, 2014). It is proposed that energy justice as a decision-making tool can support stakeholders, policymakers and planners in choosing more conscious energy decisions to achieve a fair and impartial balance between energy trilemma issues (Heffron et al., 2015; Sovacool et al., 2017). Energy trilemma can be shown as Fig. 1, which climate change, energy poverty and energy security are three vertices of triangle and energy justice is in the center (McCauley, 2017).

The potential of waste-to-energy (WTE) conversion has been considered for effective sustainable waste management (SWM) in

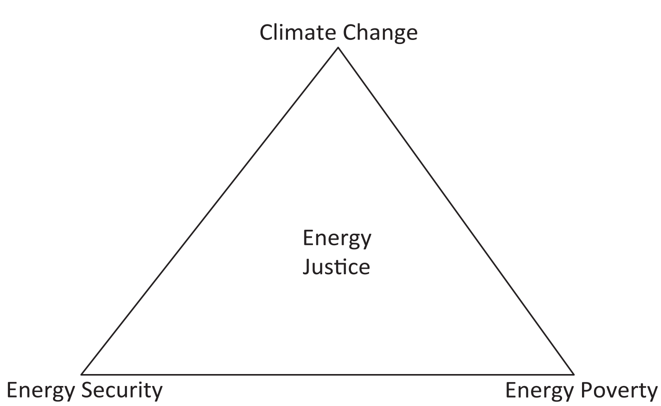

Fig. 1. Energy justice triangle.

advanced countries and about 5% of energy demand is provided through this (Brunner and Rechberger, 2015). WTE facilities as a subset of the global energy system are effectively linked to energy issues. WTE conversion affects energy security due to causing diversity in energy carriers, and also, it can help reduce energy poverty by creating jobs and increasing local household income. Choosing the right method for converting waste into energy instead of the landfill, prevents local pollution of water and soil and reduces greenhouse gas emissions (Quadrelli and Peterson, 2007). It also can decrease the demand for environmentally hazardous energy carriers.

Iran with an area of over 1.5 M km^2 and a population of about 80 M is considered one of the 20 largest and most populous countries in the world. About three-quarters of the population of Iran live in cities. The organization of waste management in Iran has a hierarchical structure. The most important national stakeholders are ministries or environmental departments and organizations affiliated with them. Local authorities and waste management organizations are the most important stakeholders at the local level. Although the landfill system is in the process of being modernized, 80% of the Iranian provinces still use informal landfill sites to dispose of waste. In some of the big cities in Iran, new methods of waste management have been used, including composting and waste incineration. Approximately 20% of urban waste in Iran is entering the process of composting or recycling. In 2015, the first modern incineration plant was set up in Tehran; it can burn up to 200 t/d of municipal solid waste ("Tehran Waste Management Organization," 2018). Organic waste with a volume of about 70% is the largest group of urban waste in Iran. In the case of industrial waste, waste generation in the oil, gas and petrochemical industry is a key challenge, especially in the southern provinces. Awareness of the Iranian people about the importance of SWM structures, including WTE technologies and the encouragement of the authorities, is the key to modernizing waste management and mitigating problems in this area.

Waste management can be considered as a supply chain problem. Waste supply chain involves waste generation, collection, separation, distribution, processing, and disposal. The efficiency of the waste chain can be enhanced by adopting suitable supply chain management methods. Examples of these methods can be found in (Gharaei et al., 2019c; Hoseini Shekarabi et al., 2018). There are many studies for deep reviews in the fields of sustainable supply chain and sustainability (Awasthi and Omrani, 2019; Gharaei et al., 2019a, 2019b; Rabbani et al., 2017; Sayyadi and Awasthi, 2018). Some of the advantages of integrating these methods into the waste chain strategies are as follows (Ekşioğlu et al., 2009; Gharaei et al., 2019c; Hoseini Shekarabi et al., 2018; Iakovou et al., 2010; Mohammadi et al., 2018; Santibañez-Aguilar et al., 2015):

- the efficient flow of waste among the chain entities,
- the transportation cost minimization,
- the inventory cost reduction,
- and the responsiveness improvement.

For instance, Zhang et al. (2011), developed an inexact reverse logistics model for investigating the interactions between inventory, transportation and production planning in municipal solid waste management systems under uncertainties. In another study, a mathematical programming model was proposed by Santibañez-Aguilar et al. (2013) for the optimal planning of the waste chain to maximize the economic benefit while taking into account technical and environmental issues. Through a study conducted by Zhang et al. (2014), a multi-echelon supply chain model involving suppliers, producers, and distributors with the aim of minimizing the system cost and cost-effective allocation of waste was proposed. A

proposed supply chain network design for efficient utilization of waste for energy generation using waste-to-energy technologies including incineration, gasification and pyrolysis was presented by Ng et al. (2014). A multi-objective model considering various functions of the waste chain for the optimal planning of the reuse waste, maximizing the annual profit, and minimizing the social risk was presented by Santibañez-Aguilar et al. (2015). They used a case study to investigate the tradeoff between the social, economic, and environmental criteria. Diaz-Barriga-Fernandez et al. (Diaz-Barriga-Fernandez et al., 2017) presented the operational planning of a waste management system. Minimizing the costs of transportation, separation, and production of the products obtained from the recycled residues and increasing the profit of all involved stakeholders were the goals of this research.

The above-mentioned studies provide important insights into the role of supply chain methods in enhancing the performance of the waste chain, taking into account both socioeconomic and environmental criteria. Nevertheless, these studies have not dealt with the application of energy justice criteria. The model proposed in this study is concerned with the selection of waste-to-energy technology as a strategic issue in the waste chain based on energy justice criteria.

Waste management is not a new issue. The expansion of urbanization and the need for higher quality of lives have increased consumerism and as a result, the quantity and quality of the waste have increased. Communities are looking for better waste management practices and also solutions that reduce the need for landfill. As can be seen in Fig. 2 (Cucchiella et al., 2017, 2014), landfill is the least desirable treatment in the waste management hierarchy but still in many countries, landfilling is the most common treatment option (Achillas et al., 2011). So using technologies such as power plants for recovering energy from waste can be a good alternative to conventional methods like landfilling. Fig. 3 shows a schematic view of a hypothetical WTE plant for burning waste and generating power. Menikpura et al. (2016) by reviewing WTE systems as the landfill alternatives in Thai cities remarked that these systems, unlike developed countries, do not have the proper financial returns. However these systems are efficient on greenhouse gas emissions, fossil resource saving, and waste volume reduction which is a major problem in East Asian countries due to population density and land shortages for waste disposal. In another study, the potential of converting waste into a renewable energy source in Mecca, Saudi Arabia, has been studied. Positive results have been achieved such as reduction in global warming, oil and natural gas saving, and revenue generation (Nizami et al., 2017).

There are various technologies for converting waste to energy, which can be categorized into three types of conversion: thermal conversion, biochemical conversion, and chemical conversion (Singh et al., 2011). These are different in a variety of ways, such as

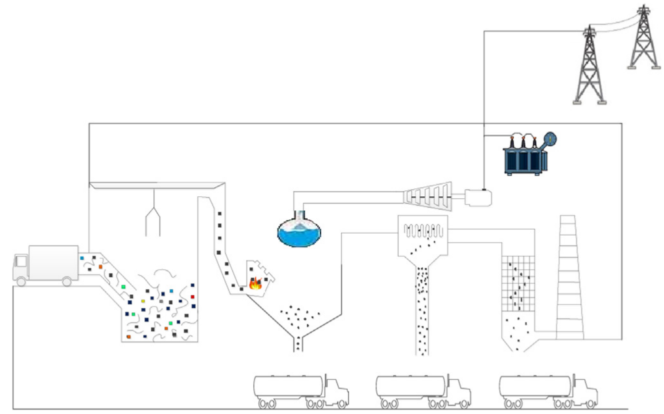

Fig. 3. Waste-to-energy power plant diagram-adopted from (Kalogirou, 2017).

initial capital costs, operational costs, time required for convert waste to energy, waste volume reduction, and amount of recovered energy. To use these technologies, along with economic and engineering dimensions, there are also social, environmental, and ethical concerns. There are concerns about failure to respect the rights of later generations (Ren et al., 2016) in decision-makings. Social opposition to the development of WTE facilities has been observed in countries with high population density (Zhao et al., 2016). Compromising among the different stakeholder priorities and the fair distribution of the benefits and costs of each action are not simple problems. Another important issue is the need to adapt the wider environmental, social, and economic consequences of each of these technologies to different regional conditions and priorities. So the choice of a comprehensive framework for decision-making is very important and selection of appropriate methods and criteria for decision-making in this area has been considered in many studies.

The variety and abundance of the criteria for choosing the appropriate treatment as well as the conflict between these criteria have led to the use of multi-criteria decision-making (MCDM) methods. Nixon et al. (2013) demonstrated an analytical hierarchy process (AHP) using expert opinions for choosing the best technology for generating energy from municipal solid waste in India. The AHP method is also used by Rahman et al. (2017) for assessment plasma gasification, pyrolysis and anaerobic digestion technologies for WTE conversion with considering financial, technological, and environmental criteria in the Dhaka city of Bangladesh. Life cycle costing and assessment (LCC and LCA), which are effective tools for calculating environmental and economic impacts, have been used frequently in researches. LCA is used to study the potential of acidification, dioxin emission, global

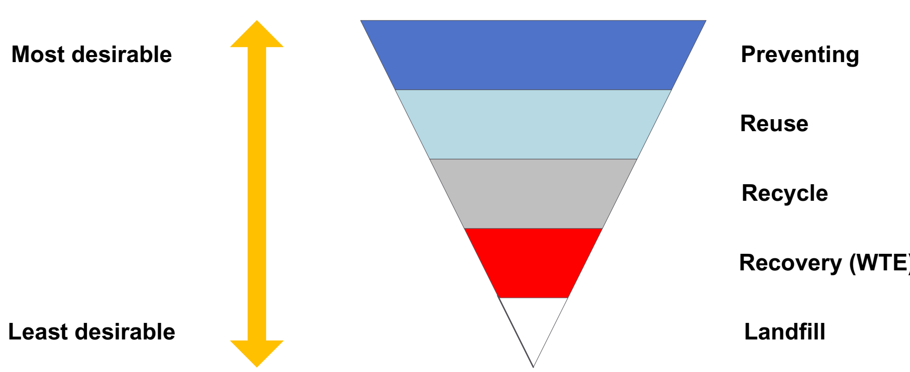

Fig. 2. The waste management hierarchy-adopted from (Cucchiella et al., 2017, 2014).

warming and electricity generation of three scenarios for producing electricity from municipal solid waste in twelve chosen cities in Nigeria (Ayodele et al., 2017). Soltani et al. (2016) used sustainable LCA for evaluating social impacts, economic, and environmental aspects of various alternatives for WTE technologies in Vancouver, Canada. They and also proposed a decision framework based on game theory and AHP that can handle conflicting preferences of various stakeholders in selecting a WTE option. Wang et al. (2018) presented a novel integrated multi-criteria decision analysis based on decision-making trail and evaluation laboratory (DEMATEL) and grey relational analysis (GRA). Their integrated method used for prioritizing the WTE treatment alternatives including incineration, gasification, anaerobic digestion, and landfill. Their work could improve the shortcomings in the uncertainties modeling, the independent relationships among the evaluation criteria, and the different priorities of multiple groups of stakeholders.

Critical analysis of the literature shows that the attempt to introduce new appropriate criteria frameworks, especially from the energy policymaking aspect, has been less on the agenda of the researchers. Most works have concentrated on the management aspects of SWM. Researches have tried to propose suitable decision making methodologies to handle the profits of different stakeholders. From a policymaking perspective, a proper criteria framework that can lead us towards sustainable development is more important than decision making methodology.

Since WTE conversion as a renewable energy resource, is a part of the energy system, the energy policymaking concepts can help the investigators for selection of a reliable criteria framework. Energy justice which is a new context in the energy policymaking has significant features that make it a proper framework for the assessment of the WTE technologies. In the matter of choosing the right WTE technology, sustainability is defined as the evaluation of social, economic and environmental impacts of the attainable options (Soltani et al., 2016). These three elements of sustainability are subsets of the principles of energy justice (see section 2.1). Choosing the principles of energy justice as an evaluation framework also involves the elements of sustainability. Another issue is that the current energy regime is in a global transition to the sustainable development. Based upon principles of sustainability any transition is unsuccessful without some form of social acceptability (McCauley, 2017). Choosing the principles of energy justice as a framework that ensures equity throughout the transition, can be a good tool to reach social acceptance. In this work, a decision-making framework has been introduced based on energy justice criteria for selecting the suitable WTE technology. Research in the last decade has shown that the concepts of energy justice are still being refined and updated (Sovacool et al., 2017, 2016). The practical implementation of these concepts can help to better understand the challenges of future research and identify the strengths and weaknesses of this structure in SWM.

1.1. Contribution of this work

Good works have been done in developing a comprehensive decision-making methodology to select the appropriate WTE technology. However the evaluation criteria used by the various researchers are not the same. It seems that there is still a shortage of providing a suitable criteria framework that can comprehensively evaluate all existing concerns in this area. The experts in the area of energy justice, ask from energy planners to use it as a decision-making tool that represent a call for even distribution of benefits and sicks at each component of the energy system and can assist them in making more informed energy choices (McCauley, 2017; Sovacool et al., 2017; Sovacool and Dworkin, 2015). WTE conversion as a subset of the global energy system has a close relationship with the energy trilemma issues. The wide range of social and ethical factors influencing the choice of appropriate waste treatment strategies, bring up the idea that the concepts of energy justice can be a good framework for decision-making in this area. In this regard, for the first time, the energy justice has been applied as a decision-making framework in selecting the appropriate technology to turn waste into energy as one of the important forms of decision-making in the field of energy trilemma. This study propose a novel combined MCDM model based on Fuzzy DEMATEL method, the analytic network process (ANP) and the simple additive weighting (SAW) approach. The proposed MCDM method has been used to select a suitable technology among possible options including incineration, pyrolysis, anaerobic digestion, and gasification for generating energy from waste in the city of Behbahan, Iran. The principles of energy justice have been considered as evaluation criteria. According to this, ten experts have been recommended to select the appropriate power plant.

2. Methods

This study introduces a framework for selecting the appropriate technology for generating energy from waste in Behbahan, Iran. This goal has been pursued by using a new decision making model consist of a decision making methodology and a criteria framework for assessing different scenarios. The criteria framework consists of four criteria and ten sub-criteria that are derived from the concepts of energy justice and are explained in section 2.1. In section 2.2, four alternatives for the conversion of waste to energy in Behbahan, Iran, are introduced and in section 2.3, the integrated MCDM method is presented based on the Fuzzy ANP, DEMATEL and SAW approaches. Fig. 4 shows the flowchart of the problem in this integrated method.

The details of the flowchart are explained in the next subsections.

Fig. 5 illustrates a summary of the decision tree with the goal of choosing the best technology for turning waste into energy.

2.1. Energy justice as criteria framework

Energy justice, which attempts to insert the concepts of ethics and justice into decision making and planning by combining the social aspect of energy with its technical aspect, can be a comprehensive framework for assessing different parts of energy systems. The use of this unified framework to evaluate actions and decisions in different sectors can ultimately help resolve major challenges in energy security, energy poverty, and climate change. Energy justice can help us for adaptation and reconciliation between conflicting tendencies in the different parts of production, distribution, and consumption of the energy. Consequently, energy justice has been chosen as a criteria framework for assessing different WTE scenarios. Criteria, sub-criteria, and details of each are represented in Table 1.

The four criteria that include the principles of energy justice and 10 sub-criteria introduced by Sovacool et al. (2017), are considered as follows:

- **2A *(C_1)*:** The two sub-criteria “Availability” and “Affordability” are in the first criterion called “2A”. Issues such as helping to supply energy to the region, diversifying energy carriers, investing and operating costs for each scenario, and creating employment and income for the local population are examined by this criterion.
- **Rights *(C_2)*:** The three sub-criteria “Intragenerational equity”, “Due process”, and “Intergenerational equity” are in the second criterion called “Rights”. This criterion is used to assess ethical

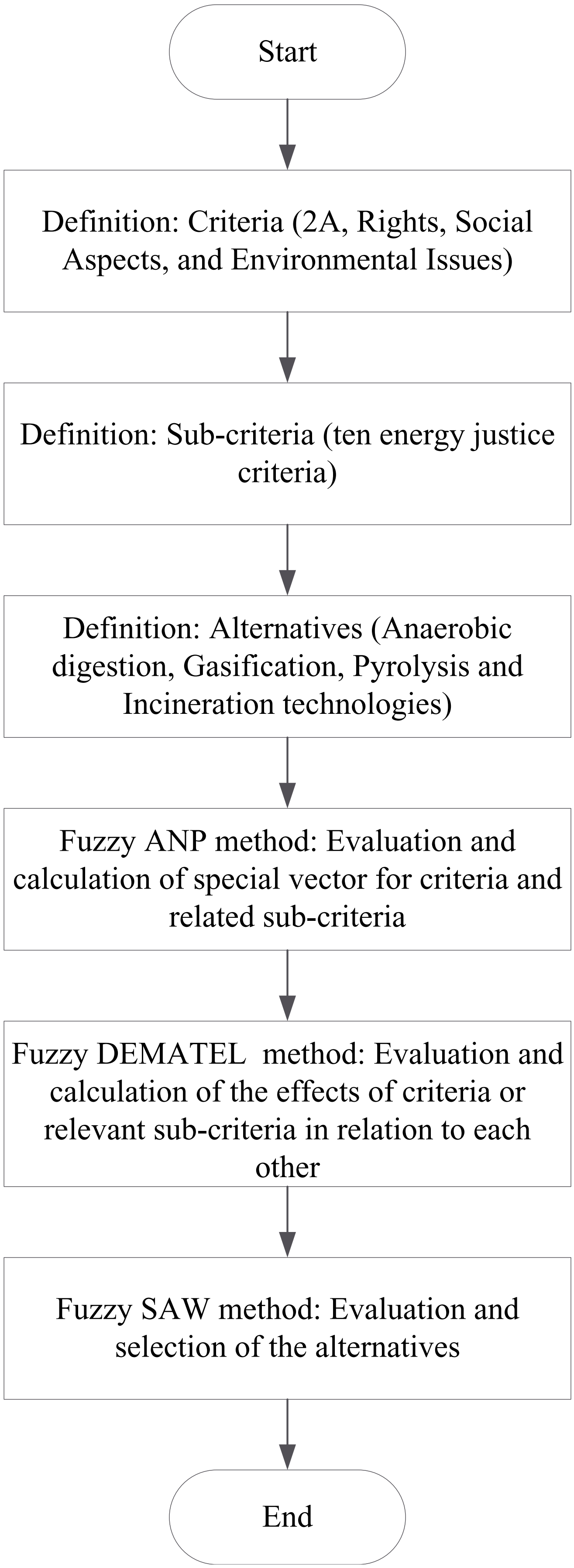

Fig. 4. The flowchart of the problem.

issues such as considering people's health in decision making, fair distribution of losses and benefits among all stakeholders, and respect for the rights of future generations.

- **Social Aspects *(C_3)*:** The three sub-criteria “Resistance”, “Transparency and accountability”, and “Intersectionality” are in the third criterion called “Social Aspects”. This criterion addresses issues such as transparency in providing information to the public and the social acceptance of each scenario, the impact of each scenario on the social and cultural development of the region, and attention to the vulnerable sections of society in decision making.
- **Environmental Issues *(C_4)*:** The two sub-criteria “Sustainability” and “Responsibility” are in the fourth criterion called “Environmental Issues”. The impact of scenarios on maintaining other energy sources, as well as concerns about water and soil pollution, toxic emissions, climate change and global warming, are included in this criterion.

The importance of each criterion in choosing the appropriate technology, as well as ranking the scenarios based on each of the criteria and relevant sub-criteria, is computed by the views of the elite and experts.

2.2. Alternatives

There are many technologies to utilize the potential of WTE conversion, and alternatives are usually suggested with consideration of geographical location, type of waste, availability of technology and skilled workforce in the region (Nizami et al., 2016). The four technologies presented below are considered as WTE scenarios in Behbahan, Iran:

i. **Incineration** (Alternative 1 (A_1)): Incineration as an appropriate alternative to landfill, which has the potential to reduce significantly waste volume (about 90%), is one of the most generally used waste management practices. Also, the thermal energy produced during the combustion of waste can be applied for heating or power generation (Cheng and Hu, 2010). The combustion residue ash is not hazardous if it is designed and executed correctly and can be used even in some construction materials (Abbott, 2003). According to the type of waste, there is a potential for toxic emissions in the chimney, which can be decreased to a satisfactory level by installing flue gas cleaning system.

ii. **Pyrolysis** (Alternative 2 (A_2)): In this process, applying heat indirectly to waste, in an environment free of oxygen, causes thermal decomposition of the waste. The products of this process are all three types of solid, oil, and gas. The temperature of the process varies between 300 and 850 °C (Appels et al., 2008), and the type of output can be determined by adjusting the temperature and the duration of the heating to the waste. For example, higher temperatures produce more gas that can be used to generate energy and the use of lower temperatures increases the proportion of liquid products that are desirable due to the ease of transfer and storage (Lombardi et al., 2015).

iii. **Anaerobic digestion** (Alternative 3 (A_3)): This biochemical conversion process is carried out at the lack of oxygen and a temperature of about 65 °C, which greatly reduces the amount of waste (Kalyani and Pandey, 2014). The remaining organic materials can be added to the soil by applying modifications. The biogas obtained from this process can be applied for heating and power production. The biogas also can be used as fuel for vehicles by making some changes to it. Since the anaerobic digestion process is only applicable to

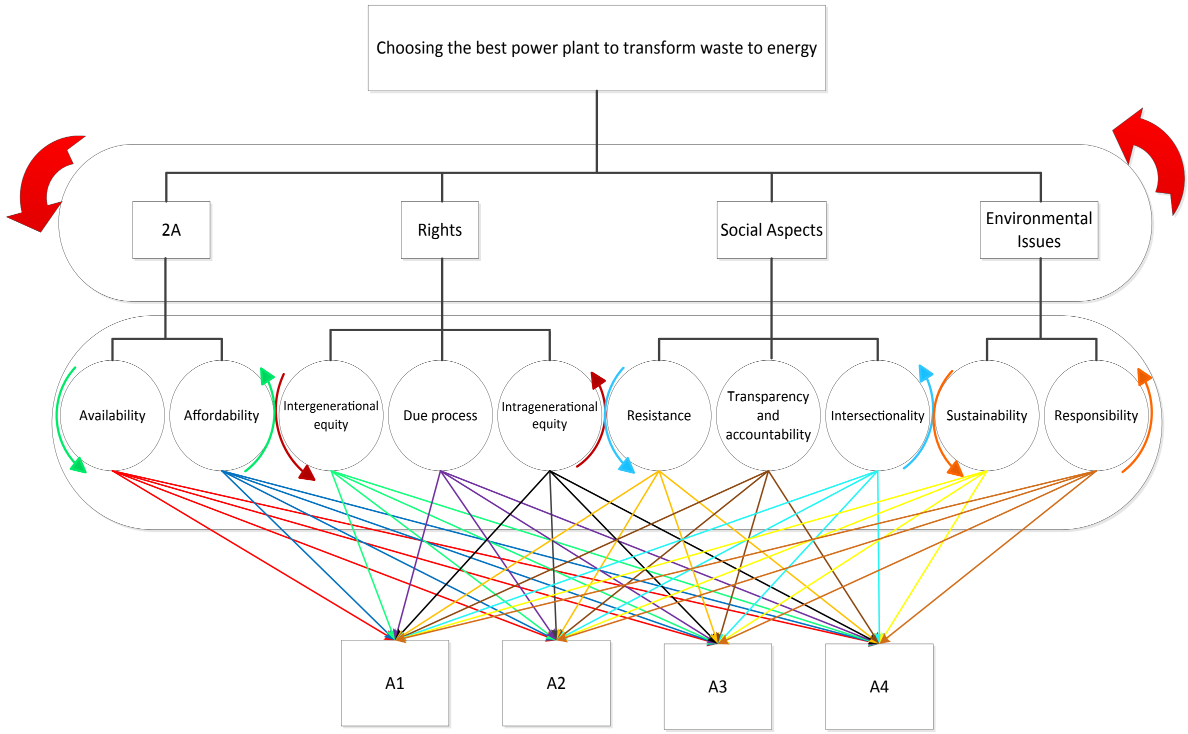

Fig. 5. The decision tree.

Table 1
The criteria and related sub-criteria and their details for the waste to energy power plant selection (Sovacool et al., 2017).

Criteria	Sub-criteria	Sub-criteria details
C_1: 2A	C_{11}: Availability	Sufficient and diverse energy sources should be available to everyone as one of the essential requirements of life.
	C_{12}: Affordability	Energy should be as cheap as possible, so that people, especially the deprived population, have no problem with their energy needs.
$C_{2:}$ Rights	C_{21}: Intergenerational equity	The right of access to energy and the benefits of it must be fair to everyone.
	C_{22}: Due process	All activities in the field of energy should be done with due respect to the due process and the human rights.
	C_{23}: Intergenerational equity	Energy activities should not endanger the right to a good life for future generations.
$C_{3:}$ Social Aspects	C_{31}: Resistance	Injustices in the production and use of energy must be confronted with public opposition.
	$C_{32:}$ Transparency and accountability	Decisions and planning should be accompanied by transparency, and the authorities must be responsive to public concerns.
	C_{33}: Intersectionality	Energy activities should be accompanied by increased awareness with the intention of identifying and eliminating injustices in various social, economic, political, and environmental areas.
$C_{4:}$ Environmental Issues	C_{41}: Sustainability	All actors must move in the direction of sustainable development and preservation of existing natural resources.
	C_{42}: Responsibility	All decisions must be made with a sense of responsibility towards the environment and in order to minimize concerns like greenhouse gas emissions, air pollution, and climate change.

the organic waste sector, it requires a waste separation unit (Malkow, 2004).

iv. **Gasification** (Alternative 4 (A_4)): In the gasification process, solid waste is transformed into a gaseous fuel by incomplete oxidation in reaction with a controlled amount of oxygen at a temperature of about 600 °C or higher. This process has a lower environmental pollution than other thermal conversion methods. The syngas obtained from the process, in addition to using in gas turbines, can be used to produce other synthetic fuels. However, production of high thermal value syngas requires high-cost oxygen supply equipment.

2.3. Integrated MCDM (IMCDM)

In this article, a decision support system is used as a compound system in decision making according to approaches, Fuzzy ANP, DEMATEL and SAW for installation and establishment of WTE in Behbahan. A schematic of new algorithm on decision making according to hierarchy is produced in Fig. 6.

In this methodology Fuzzy ANP for reaching the goal and criteria, criteria and relevant sub-criteria is applied. Considering the criteria's influence on each other, the impact on the other parts of criteria and related sub-criteria is shown by Fuzzy DEMATEL. Fuzzy SAW is used for calculation of decision making matrix of sub-criteria with the use of alternatives.

The above methods have been employed in a matrix known as the super matrix as follows:

$$\begin{array}{c c} & GoalCriteriaSub-criteia \\ \begin{array}{c} Goal \\ Criteria \\ Sub-criteria \end{array} & \begin{bmatrix} 1 & 0 & 0 \\ w_{21} & W_{22} & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \end{array}$$

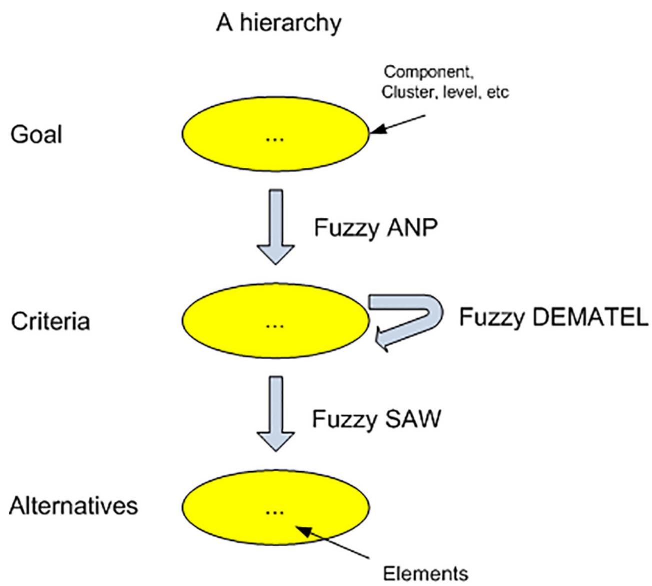

Fig. 6. Integrated decision making algorithm (Fetanat and Khorasaninejad, 2015; Khorasaninejad et al., 2016).

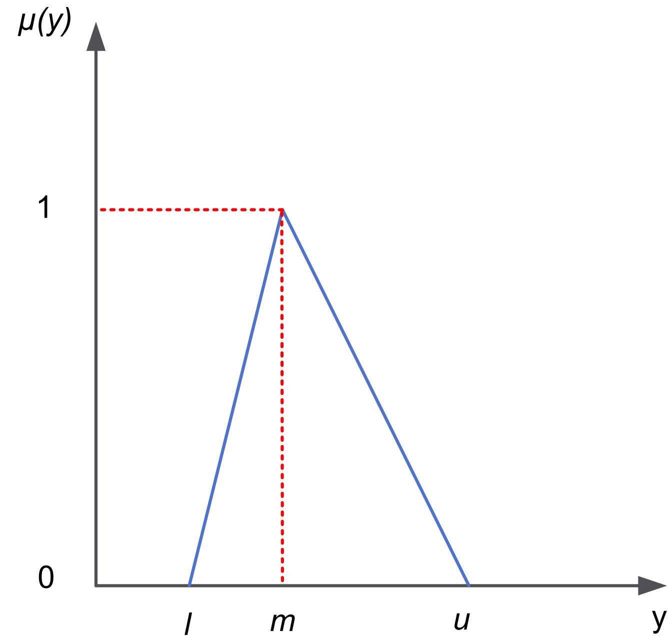

Fig. 7. A fuzzy number-adopted from (Fetanat et al., 2019).

for the goal into criteria, w_{21} is the eigenvector of the aggregated comparison matrix, and $W_{32,}$ is a matrix, includes of eigenvectors of the aggregated comparison matrices, W_{22} is the aggregated comparison matric for effectiveness of criteria into each other, and W_{33} is the aggregated comparison matric for effectiveness of sub-criteria into each other. By exponentiation of the final achieved super matrix, the new matrix is calculated. According to sub-criteria in the super matrix, the vector of elements of goal column is weighed vector. This vector is applied in the Fuzzy SAW method. In the following, the mentioned methods are discussed in details.

2.3.1. Fuzzy number

One of the basic methods for dealing with vague terms is the use of fuzzy theory. Decision makers decide on their past experiences and their knowledge and their decisions are often estimations of a function of linguistic terms. For this purpose, to complete the experiences and ideas of decision makers, it is better to convert the linguistic estimation to the fuzzy number. In fuzzy theory, a membership function $\mu_{A}(y)$ represents a mapping μ_{A}: $\tilde{A} \rightarrow$ [0, 1]. The $\mu_{A}(y)$ is known as the membership value. It shows the degree of truth that y is an element of fuzzy set $\tilde{A}$, Y (a universal set) and$\tilde{A} \subset Y$. It is assumed that $\mu_{A}(y)$ ε [0, 1], where $\mu_{A}(y) = 1$ reveals that y belongs completely to $\tilde{A}$, while $\mu_{A}(y) = 0$ indicates that y does not belong to the fuzzy set $\tilde{A}$ (Lin and Wu, 2008). A triangular fuzzy number $\tilde{A}$ can be defined as a triplet (l, m, u), and $\mu_{A}(y)$ is identified as

$$\mu\tilde{A} \cdot (y) = \begin{cases} 0 & y < l \\ (y-l)/(m-l) & l \le y \le m \\ (u-y)/(u-m) & m \le y \le u \\ 0 & y > u \end{cases}$$

where $l \le m \le u$ and l, m, and u are real numbers. See Fig. 7.

Linguistic variables are applied as variables whose values are not numbers, but are defined using linguistic terms of these variables. Decision makers use the linguistic variable approach to deal with uncertain and unclear conditions for quantitative expressions for their analysis, which could be helpful in this regard. The linguistic statements can be shown with fuzzy numbers, which are usually used in particular triangular fuzzy numbers.

2.3.2. Fuzzy ANP method

The general form of analysis hierarchical process was made for MCDM. ANP is a decision-making technique that is very similar to the AHP method. Each method is based on a series of assumptions. For example, if the criteria are independent and paired comparisons are possible, the appropriate decision method is the AHP model, but if the criteria are not independent, the ANP method is better. In most of the real issues, there are different types of dependencies between the elements in the problem, including the dependence between decision criteria. For this reason, ANP, which is able to apply all the dependencies of the elements in the problem, has been raised. In this article, this method is used for evaluation and calculation of special vector for criteria and related sub-criteria. The steps of the above method are as follows (Fetanat and Khorasaninejad, 2015; Khorasaninejad et al., 2016):

1: Initially the vector of special criteria and relevant sub-criteria are obtained for super matrix. The criteria and related sub-criteria were compared by a society of experts (N experts). The question is asked from each of the expert: Mention the importance of any of the criteria and relevant sub-criteria relations to each other? Relative importance of each criterion in fuzzy numbers is mentioned in Table 2.
2: The experts' answers are in the triangular numbers, which are stored in the matrix and then stored by a geometric mean in a matrix. The sample of fuzzy triangular number is as follows for the relative importance of criteria i and j:

$$l_{i,j} = \sqrt[N]{\Pi_{k=1}^{N} F_{ijk}}\ ,\ m_{i,j} = \sqrt[N]{\Pi_{k=1}^{N} F_{ijk}},\ u_{i,j} = \sqrt[N]{\Pi_{k=1}^{N} F_{ijk}} \tag{1}$$

F_{ijk} is the pairwise comparison value between criteria i and j calculated by expert k.

3: Any triangular number is defuzzified in the following Yager relation (Lee et al., 2012):

Table 2
The fuzzy number for ANP approach (Fetanat and Khorasaninejad, 2015; Khorasaninejad et al., 2016).

Linguistic term	Fuzzy number
Equal	(1, 1, 1.5)
Very little high	(1.5, 2.5, 3.5)
Little high	(2.5, 3.5, 4.5)
Moderately High	(3.5, 4.5, 5.5)
High	(4.5, 5.5, 6.5)
Very high	(5.5, 6.5, 7.5)
Very big high	(6.5, 7.5, 8.5)
Extremely high	(7.5, 8.5, 9)

$$\tilde{A}_{i,j} = \int_0^1 \frac{1}{2}\left(\left(\tilde{A}_{i,j}\right)^l_\alpha + \left(\tilde{A}_{i,j}\right)^u_\alpha\right)\, d\alpha = \frac{l_{i,j} + 2m_{i,j} + u_{i,j}}{4} \tag{2}$$

where $\tilde{A}$ is a fuzzy number.

4: With calculating the matrix obtained in the above ways for criteria and relevant sub-criteria, the eigenvector is calculated as follows:

$$W \times w = \psi_{max} \times w \tag{3}$$

W is the matrix obtained from step 3, w is the eigenvector and ψ_{max} is the biggest eigenvalue of W.

5: Compatibility traits of matrix obtained are calculated and then the consistency index (CI) and consistency ratio (CR) are defined as follows (Wang, 2015):

$$CI = \frac{\psi_{\max} - n}{n-1} . CR = \frac{CI}{RI} \tag{4}$$

In the matrix, n shows the number of items which are being compared. RI is a random number according to Table 3 and if CR is bigger than its threshold number the question will be asked again from the experts.

2.3.3. Method of fuzzy DEMATEL

Fuzzy DEMATEL method was developed to evaluate complex problems in the world (Asgharpour, 2011). One of the useful applications of this method is to solve problems related to causal connections among intricate factors. This technique examines the severity of the communication, traces backward feedback with their importance, and accepts non-transferable relationships. The advantage of this approach to ANP is its clarity and transparency in reflecting interactions among a wide range of components. Fuzzy DEMATEL method can help experts to be more definitive in expressing their opinions about the direction and severity of effects between factors. The DEMATEL method can be used as part of an inhomogeneous matrix in the ANP method. The DEMATEL technique does not work independently in this mode, but can be integrated as part of a larger system such as ANP. To reach the main vector from comparison matrix, method of Fuzzy DEMATEL is being used for the effects of criteria or relevant sub-criteria in relation to each other. Stages of calculation of Fuzzy DEMATEL are in the following forms (Büyüközkan and Çifçi, 2012):

Table 3
The random index (Fetanat and Khorasaninejad, 2015; Khorasaninejad et al., 2016).

Matrix	2 × 2	3 × 3	4 × 4	5 × 5	6 × 6
RI	0	0.58	0.9	1.12	1.24

1: The effects of criteria or relevant sub-criteria on each other are compared by N experts. The work is accomplished via twin questioning as mentioned below:

Considering the profits and preferences, how much influence does a criterion or sub-criterion has on another one?

According to Table 4, the relative permeation is calculated by a fuzzy number.

2: By the use of arithmetic mean method from the triangular numbers together, the answer for the experts committee is obtained. The attained matrix is also known the fuzzy initial direct relation matrix (Z). For example, the fuzzy number for the relative permeations between criteria i and j is computed in the following forms:

$$l'_{i,j} = \frac{1}{N}\sum_{k=1}^{N} F'_{ijk},\ m'_{i,j} = \frac{1}{N}\sum_{k=1}^{N} F'_{ijk},\ u'_{i,j} = \frac{1}{N}\sum_{k=1}^{N} F'_{ijk} \tag{5}$$

where F'_{ijk} is the relative influence value between criteria i and j computed by expert k.

3: Fuzzy initial direct relation matrix is normalized as follows:

$$\tilde{Y} = \left(1/\max_{1\le i\le n_C} \sum_{j=1}^{n_C} u'_{ij}\right) \times \tilde{Z} \tag{6}$$

In this formula, parameter n_C is the number of the criteria or related sub-criteria in the relevant matrices.

4: In the following method, the fuzzy total-relation matrix is obtained:

1 The elements of $\tilde{Y}_{ij} = (l'_{ij},\ m'_{ij},\ u'_{ij})$ are exploited as three crisp matrices in the following forms:

$$X_1 = \begin{bmatrix} 0 & l'_{12} & \cdots & l'_{1n} \\ l'_{21} & 0 & \cdots & l'_{2n} \\ \vdots & & & \vdots \\ l'_{n1} & l'_{n2} & \cdots & 0 \end{bmatrix}, \quad X_2 = \begin{bmatrix} 0 & m'_{12} & \cdots & m'_{1n} \\ m'_{21} & 0 & \cdots & m'_{2n} \\ \vdots & & & \vdots \\ m'_{n1} & m'_{n2} & \cdots & 0 \end{bmatrix}, \quad X_3 = \begin{bmatrix} 0 & u'_{12} & \cdots & u'_{1n} \\ u'_{21} & 0 & \cdots & u'_{2n} \\ \vdots & & & \vdots \\ u'_{n1} & u'_{n2} & \cdots & 0 \end{bmatrix} \tag{7}$$

2 The total-relation fuzzy matrix $\tilde{T}$ is defined as follows:

Table 4
The fuzzy number for DEMATEL approach (Fetanat and Khorasaninejad, 2015; Khorasaninejad et al., 2016).

Linguistic term	Fuzzy number
No influence	(0, 0, 0.25)
Very low influence	(0, 0.25, 0.5)
Low influence	(0.25, 0.5, 0.75)
High influence	(0.5, 0.75, 1)
Very high influence	(0.75, 1, 1)

$$T_1 = X_1(I - X_1)^{-1}, \quad T_2 = X_2(I - X_2)^{-1}, \quad T_3 = X_3(I - X_3)^{-1} \cdot \tilde{T} = (T_1, \quad T_2, \quad T_3) \tag{8}$$

5: For calculation the inner dependence matrix, matrix $\tilde{T}$ is defuzzified by Yager relation.
6: The sum of rows and the sum of columns are separately denoted as D and R through the formulas (9)–(11) (Wu, 2012).

$$T = [t_{ij}], \quad i,j = 1, \ 2, \ \ldots, \ n_C \tag{9}$$

$$D_i = \sum_{j=1}^{n_C} t_{ij} \quad i = 1, \ 2, \ \ldots, \ n_C \tag{10}$$

$$R_j = \sum_{i=1}^{n_C} t_{ij} \quad j = 1, \ 2, \ \ldots, \ n_C \tag{11}$$

where D_i and R_j interpret the totals of rows and columns. Then D_i shows summation of direct and indirect traces that the agent (factor) i has given to other agents and R_j represents the total results, both direct and indirect collected by an agent j given by other agents. A causal diagram can be obtained by plotting the dataset of ($D_i + R_{j=i}$, $D_i - R_{j=i}$), where the lateral axis is $D_i + R_{j=i}$, and the vertical axis is D_i- $R_{j=i}$. When $i = j$, then the term $(D_i + R_j)$ shows the degree of significance of the factor, and $(D_i - R_j)$ shows the net outcome that the agent contributes to the system subject to other agents. If $(D_i - R_j)$ is positive, the factor i is pure causer, and if it is negative, agent i is a pure recipient (Tzeng et al., 2007).

2.3.4. Calculation of super matrix

In this stage, eigenvectors of Fuzzy ANP method and criteria and sub-criteria of inner dependent matrices of Fuzzy DEMATEL method are located inside the unweighted super matrix. Each column number is divided by the total of the numbers of that column. New matrix obtained according to the power of the mentioned matrix. In the super matrix, the Goal column and sub-criteria rows express the decision weighted vector. These weights obtained are used in SAW method for ranking of the options.

2.3.5. Fuzzy SAW method

The SAW method is introduced to solve Fuzzy MCDM problems. This method is the oldest, most widely known and practically used method for selecting in the MCDM. The procedure of SAW as follows (Wang, 2015):

1: The comparison among alternatives with the co-signer based on the features of their sub-criteria is done to select the best option.

This is achieved via N experts. The experts are wanted to pairwise compare as follows: How much is an alternative superior to other alternatives according to its sub-criteria?

By a fuzzy number as noted in Table 5, the priority value is calculated. In Fig. 8, for m_{alt} alternatives and n_{sub} sub-criteria, the decision matrix is represented.

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_{m_{alt}} \end{array} \begin{array}{c} \begin{array}{cccc} SC_1 & SC_2 & & SC_{n_{sub}} \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n_{sub}} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n_{sub}} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m_{alt}1} & \tilde{x}_{m_{alt}2} & \cdots & \tilde{x}_{m_{alt}n_{sub}} \end{bmatrix} \end{array}$$

in this matrix, the alternatives are A_i, $i=1, 2, \ldots, m_{alt}$, and the sub-criteria are SC_j, $j=1,2, \ldots, n_{sub}$.

Table 5
The fuzzy number for SAW approach (Fetanat and Khorasaninejad, 2015; Khorasaninejad et al., 2016).

Linguistic term	Fuzzy number
None	(0, 0, 0.1)
Very low	(0, 0.1, 0.2)
Low	(0.1, 0.2, 0.3)
Fairly low	(0.2, 0.3, 0.4)
More or less low	(0.3, 0.4, 0.5)
Medium	(0.4, 0.5, 0.6)
More or less good	(0.5, 0.6, 0.7)
Fairly good	(0.6, 0.7, 0.8)
Good	(0.7, 0.8, 0.9)
Very good	(0.8, 0.9, 1)
Excellent	(0.9, 1, 1)

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_{m_{alt}} \end{array} \begin{array}{c} \begin{array}{cccc} SC_1 & SC_2 & & SC_{n_{sub}} \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n_{sub}} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n_{sub}} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m_{alt}1} & \tilde{x}_{m_{alt}2} & \cdots & \tilde{x}_{m_{alt}n_{sub}} \end{bmatrix} \end{array}$$

Fig. 8. The fuzzy decision matrix.

2: The arithmetic average method is applied to collect the committee of experts' answers and the fuzzy numbers are computed.
3: By Yager formula, the fuzzy numbers are defuzzified.
4: The defuzzified matrix is normalized in the following form:

$$norm_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m_{alt}} r_{ij}}} \tag{12}$$

5: A weighted decision matrix from the matrix of step 4 is produced as follows:

$$norm_{ij} \times \ W_{alt,} \tag{13}$$

where W_{alt} is the final priorities of the options.

6: The evaluation indices of the alternatives from the matrix of step 5 are obtained as follows:

$$A'_i = \sum_{j=1}^{n_{sub}} norm_{ij} \times \ W_{alt,} \tag{14}$$

7: Grade alternatives by using relevant evaluation indices. Alternatives A_1, A_2, …, A_{malt} are prioritized conforming to the pertinent evaluation indices A'_1, A'_2, …, A'_{malt}. The largest value of these indices corresponds to the better the option.

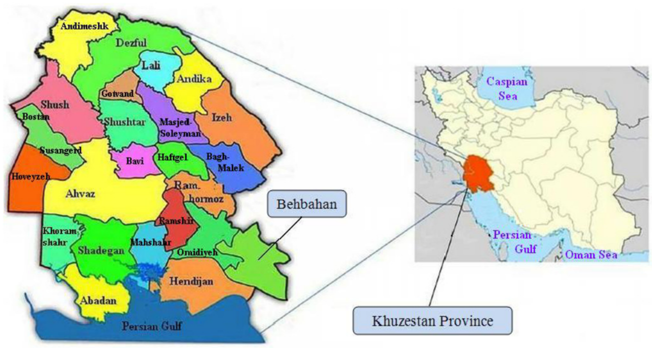

Fig. 9. The study area (Fetanat et al., 2019).

3. Results and discussion

3.1. Case study

The city of Behbahan is located in the Khuzestan province and covers 3715 km^2 area considered as 10th city in the province (See Fig. 9).

The major part of city's waste is related to the domestic and agricultural sectors. After collection, the waste is buried in the marginal areas of the city, regardless of the engineering needs, which results in the loss of land and pollution of water and soil. Sometimes the waste is burnt in a non-standard way without energy recovery. The garbage left in suburban recreation areas by individuals has increased the environmental pollution and ugliness of the city's face. The bad effects of climate change, such as the appearance of dust, drought, rising air temperatures, and air pollution caused by the activity of numerous oil and gas industries in this region, clarify the need to use new sources of energy instead of fossil fuels. Incineration, pyrolysis, anaerobic digestion, and gasification have been studied to select the appropriate technology for generating energy from waste in the Behbahan city. A new integrated MCDM model has been used that operates based on the energy justice concepts as evaluation criteria.

There were limitations to doing this research in Behbahan, which could also affect the findings of this study. The novelty of these concepts as well as the lack of use of them as a framework so far, has made it difficult to find experts in this area. By organizing several interviews with a group of elites in the city, these new subjects were explained. Finally, the ten experts in different organizations like university, city community, and electrical department are wanted to contribute their expertise in power plant technology selection. Another point to note is that the waste disposal of the city is already in a definite place and the location of the WTE plant will be in the same area. The location of this plant can affect the views of the elites about different technologies and, consequently, influence the weight factors of decision making methods in this research. Considering the importance of the waste disposal site and the WTE plant, the location of the new disposal site as well as the location of the WTE plant in the city, according to the sustainability criteria, can be studied in future studies.

This research examines the feasibility of utilizing the potential of the city in the field of waste and energy with the aim of approaching sustainable development criteria. The implementation of this plan will require the mental preparation of the community and the relevant authorities. It will be helpful to inform new concepts in the area of sustainable management and energy policy, to create new disciplines in the universities of the region, and to invite national and international elites in the field of energy and environmental policy and management.

3.2. Computations of integrated MCDM

The numerical values of proposed model are:

3.2.1. Fuzzy ANP

The defuzzified aggregated pairwise comparison matrix is:

$$W_{21} = \begin{bmatrix} 1.1250 & 0.1849 & 0.1849 & 0.1557 \\ 5.5000 & 1.1250 & 0.1849 & 5.5000 \\ 5.5000 & 0.1849 & 1.1250 & 0.2984 \\ 1.1250 & 0.1849 & 2.5000 & 1.1250 \end{bmatrix}$$

The priority vector and $\psi_{\max}$ are obtained:

$$w_{21} = \begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \end{array} \begin{bmatrix} 0.0795 \\ 0.4524 \\ 0.2183 \\ 0.2498 \end{bmatrix}$$

$$\psi_{\max} = 3.9393$$

The preformation of consistency is defined by computing *CI* and *CR*:

$$CI = \frac{\psi_{\max} - n}{n-1} = \frac{3.9393 - 4}{4-1} = -0.0202$$

$$CR = \frac{CI}{RI} = \frac{-0.0202}{0.9} = -0.0224$$

The experts' judgments are consistent when $CR \leq 0.1$. If $CR > 0.1$ then the experts are wanted to complete the specific part of the questionnaires afresh. Priority vectors are obtained in a similar way:

$$w_{32-1} = \begin{array}{c} \\ C_{11} \\ C_{12} \end{array} \begin{array}{c} C_1 \\ \begin{bmatrix} 0.1196 \\ 0.8804 \end{bmatrix} \end{array} \quad w_{32-2} = \begin{array}{c} \\ C_{21} \\ C_{22} \\ C_{23} \end{array} \begin{array}{c} C_2 \\ \begin{bmatrix} 0.6556 \\ 0.2752 \\ 0.0692 \end{bmatrix} \end{array} \quad w_{32-3} = \begin{array}{c} \\ C_{31} \\ C_{32} \\ C_{33} \end{array} \begin{array}{c} C_3 \\ \begin{bmatrix} 0.0719 \\ 0.7204 \\ 0.2077 \end{bmatrix} \end{array} \quad w_{32-4} = \begin{array}{c} \\ C_{41} \\ C_{42} \end{array} \begin{array}{c} C_4 \\ \begin{bmatrix} 0.8203 \\ 0.1797 \end{bmatrix} \end{array}$$

3.2.2. Fuzzy DEMATEL

The fuzzy aggregated pairwise comparison matrix, according the criteria, is calculated and has been shown as follows:

$$\tilde{W}_{22} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} (0.75, 1.00, 1.00) & (0.25, 0.50, 0.75) & (0.25, 0.50, 0.75) & (0.50, 0.75, 1.00) \\ (0.50, 0.75, 1.00) & (0.75, 1.00, 1.00) & (0.50, 0.75, 1.00) & (0.00, 0.25, 0.50) \\ (0.50, 0.75, 1.00) & (0.00, 0.25, 0.50) & (0.75, 1.00, 1.00) & (0.00, 0.25, 0.50) \\ (0.50, 0.75, 1.00) & (0.25, 0.50, 0.75) & (0.50, 0.75, 1.00) & (0.75, 1.00, 1.00) \end{bmatrix} \end{array}$$

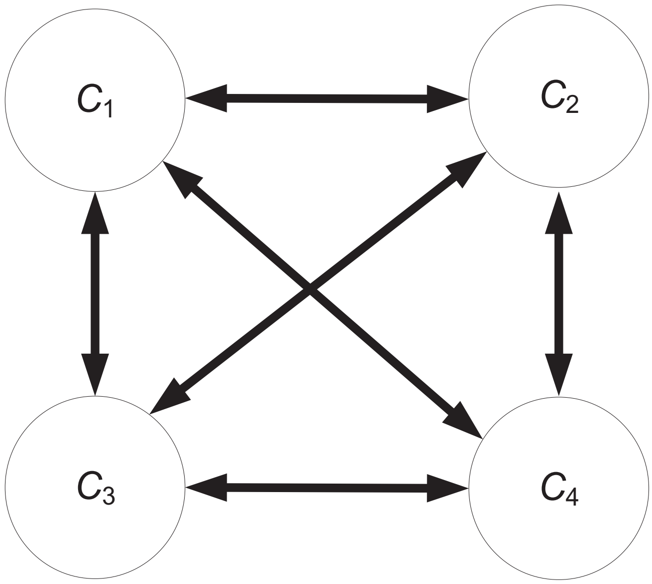

Fig. 10. The interrelationships between criteria.

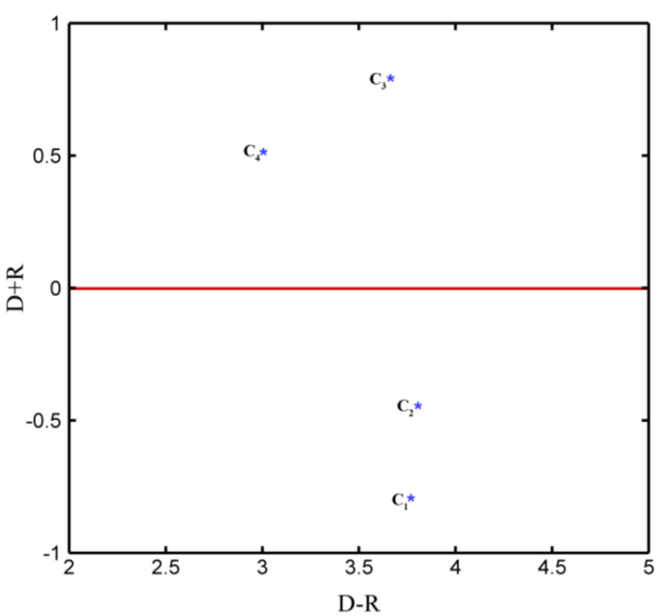

Fig. 11. The causal diagram.

The inner dependence matrix is:

$$W_{22} = \begin{bmatrix} 0.2645 & 0.5941 & 0.4343 & 0.5041 \\ 0.3183 & 0.3917 & 0.3448 & 0.6186 \\ 0.3773 & 0.7036 & 0.3463 & 0.7932 \\ 0.2956 & 0.4901 & 0.3202 & 0.3749 \end{bmatrix}$$

The interrelationships among the criteria and the causal diagram are shown in Fig. 10 and Fig. 11.

Looking at this causal diagram, two groups of evaluation criteria are the cause group including C_3, C_4 and the non-dominant group including C_2, C_1. In a familiar way, the inner dependence matrix is calculated for the effect of the sub-criteria subject to the same upper-level criterion:

$$W_{33-1} = \begin{bmatrix} 0.4432 & 0.4261 \\ 1.0659 & 0.4432 \end{bmatrix}$$

$$W_{33-2} = \begin{bmatrix} 0.4807 & 0.4539 & 0.5106 \\ 0.8601 & 0.4807 & 0.7640 \\ 0.7640 & 0.5106 & 0.4807 \end{bmatrix}$$

$$W_{33-3} = \begin{bmatrix} 0.6799 & 0.6388 & 1.0681 \\ 0.5749 & 0.4013 & 0.6388 \\ 0.7896 & 0.5749 & 0.6799 \end{bmatrix}$$

$$W_{33-4} = \begin{bmatrix} 0.8214 & 0.8095 \\ 1.3482 & 0.8214 \end{bmatrix}$$

3.2.3. *Super matrix calculation*

The super matrix as normalized matrix is shown as Table 6.

In this table, C_1, C_2, C_3 and C_4 are criteria and SC_1, SC_2, SC_3 and SC_4 are the sub-matrices of the sub-criteria (according to Table 1).

To obtain the weighted super matrix, the normalized super matrix is powered about 1000. In this matrix and in the “Goal” column, the weights of the sub-criteria are as follows:

$$w_{alt} = \begin{bmatrix} 0.0892 \\ 0.1285 \\ 0.0774 \\ 0.1063 \\ 0.0904 \\ 0.1219 \\ 0.0839 \\ 0.1076 \\ 0.0865 \\ 0.1083 \end{bmatrix}$$

Total of the above vector members are always one.

3.2.4. *Fuzzy SAW*

For the alternatives, the aggregate decision matrix is calculated in the following form.

$$w_{ff} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccccccccc} C_{11} & C_{12} & C_{21} & C_{22} & C_{23} & C_{31} & C_{32} & C_{33} & C_{41} & C_{42} \end{array} \\ \begin{bmatrix} (0.6,0.7,0.8) & (0.7,0.8,0.9) & (0.6,0.7,0.8) & (0.6,0.7,0.8) & (0.1,0.2,0.3) & (0,0.1,0.2) & (0.3,0.4,0.5) & (0.3,0.4,0.5) & (0.3,0.4,0.5) & (0,0.1,0.2) \\ (0.9,1,1) & (0.9,1,1) & (0.7,0.8,0.9) & (0.7,0.8,0.9) & (0,0.1,0.2) & (0.2,0.3,0.4) & (0.5,0.6,0.7) & (0.5,0.6,0.7) & (0.5,0.6,0.7) & (0.2,0.3,0.4) \\ (0.9,1,1) & (0.6,0.7,0.8) & (0.9,1,1) & (0.9,1,1) & (0.7,0.8,0.9) & (0.4,0.5,0.6) & (0.9,1,1) & (0.9,1,1) & (0.9,1,1) & (0.4,0.5,0.6) \\ (0.4,0.5,0.6) & (0.5,0.6,0.7) & (0.5,0.6,0.7) & (0.5,0.6,0.7) & (0.3,0.4,0.5) & (0.5,0.6,0.7) & (0.7,0.8,0.9) & (0.7,0.8,0.9) & (0.7,0.8,0.9) & (0.1,0.2,0.3) \end{bmatrix} \end{array}$$

Table 6
The normalized super matrix.

	Goal	C_1	C_2	C_3	C_4	SC_1	SC_2	SC_3	SC_4
Goal	1	0	0	0	0	0	0	0	0
C_1						0	0	0	0
C_2						0	0	0	0
C_3	w_{21}			W_{22}		0	0	0	0
C_4						0	0	0	0
SC_1	0	w_{32_1}	0	0	0	W_{33_1}	0	0	0
SC_2	0	0	w_{32_2}	0	0	0	$W_{33\text{-}2}$	0	0
SC_3	0	0	0	w_{32_3}	0	0	0	$W_{33\text{-}3}$	0
SC_4	0	0	0	0	w_{32_4}	0	0	0	$W_{33\text{-}4}$

The normalized decision matrix and then the weighted decision matrix are obtained as follows:

$$R = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccccccccc} C_{11} & C_{12} & C_{21} & C_{22} & C_{23} & C_{31} & C_{32} & C_{33} & C_{41} & C_{41} \end{array} \\ \begin{bmatrix} 0.4307 & 0.5121 & 0.4625 & 0.4481 & 0.2169 & 0.1187 & 0.2753 & 0.2753 & 0.2753 & 0.4376 \\ 0.5999 & 0.6241 & 0.4625 & 0.5121 & 0.1085 & 0.3560 & 0.4130 & 0.4130 & 0.4130 & 0.4376 \\ 0.5999 & 0.4481 & 0.6442 & 0.6241 & 0.8677 & 0.5934 & 0.6711 & 0.6711 & 0.6711 & 0.7293 \\ 0.3077 & 0.3841 & 0.3964 & 0.3841 & 0.4339 & 0.7121 & 0.5507 & 0.5507 & 0.5507 & 0.2917 \end{bmatrix} \end{array}$$

$$V = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccccccccc} C_{11} & C_{12} & C_{21} & C_{22} & C_{23} & C_{31} & C_{32} & C_{33} & C_{41} & C_{42} \end{array} \\ \begin{bmatrix} 0.0384 & 0.0658 & 0.0358 & 0.0476 & 0.0196 & 0.0145 & 0.0231 & 0.0296 & 0.0238 & 0.0476 \\ 0.0535 & 0.0802 & 0.0358 & 0.0544 & 0.0098 & 0.0434 & 0.0347 & 0.0444 & 0.0357 & 0.0474 \\ 0.0535 & 0.0576 & 0.0498 & 0.0664 & 0.0784 & 0.0723 & 0.0563 & 0.0722 & 0.0581 & 0.0790 \\ 0.0274 & 0.0494 & 0.0307 & 0.0408 & 0.0392 & 0.0868 & 0.0462 & 0.0592 & 0.0476 & 0.0316 \end{bmatrix} \end{array}$$

The alternative evaluation indices are:
$A'_1 = 0.3457$, $A'_2 = 0.4394$, $A'_3 = 0.6436$, $A'_4 = 0.4590$.

These indices are sorted and according to the above, $A_3 > A_4 > A_2 > A_1$ (> is a symbol for preference relations), the ranking shows that alternative A_3 (anaerobic digestion) is the best alternative. As a result, the anaerobic digestion is chosen as the best option to turn waste into energy in Behbahan. Low investment and operating costs, good economic returns, eco-friendliness and high public acceptance are the strengths of anaerobic digestion. At the same time, the compatibility of this method with the regional conditions of the city has helped to make it the best choice. In Behbahan, as a small town, most activities are related to agriculture and households, and the major part of the waste is organic material. In terms of sustainability context, sustainable waste management is a sustainable waste supply chain management and for this reason, sustainability items in this research are considered. Sustainability factors like social, environmental, economic and technical aspects in sustainable waste management have been investigated in energy justice concept. Four criteria and ten sub-criteria in energy justice context are applied in decision making framework. The weights of the sub-criteria are shown in final vector in section 3.2.3. According to the weights, Affordability and Resistance have the most effects and Intragenerational equity has the least effect in sub-criteria.

As a result, the anaerobic digestion is a good option for this type of waste, and the remaining organic material from this process can be used to strengthen agricultural soil in the region. Another issue is that Behbahan is located in a tropical region, and the air temperature in some months reaches more than 50 °C. The anaerobic digestion, which is performed at a much lower temperature (about 65 °C) compared with other options and can also prevent global warming through methane capture (Abbasi et al., 2012), seems to be the best option.

4. Policy implications

In this study, there are four alternatives for WTE technologies in sustainable waste management. Accepting the mathematical theory of a hybrid MCDM, energy justice criteria and related concepts, a number of implications for WTE policies can be replaced with the previous sections.

I. What makes WTE an important candidate for energy justice based decision making applications?

Interaction between the above-mentioned WTE technologies is an important part of energy policies that is to be evaluated. Applying energy justice based decision making frameworks that provide precise descriptions of situations of conflicting interests, would be good choices. In this way, policy formulation and implementation is shaped by their interactions.

II. Do not worry about the development of power plants when a limited number of conflicting criteria can be chosen.

As population increases and availability of energy resources such as natural gas and water decreases or remain constant, the potential for other energies like WTE becomes more. In this situation, technology behaviors by these alternatives become more essential if they are to maintain their society and environment. Based on these, this paper provides guidelines based on energy justice principles or criteria (10 criteria) for arrangements that increase the stability of policies aimed at improving performances of WTE.

5. Conclusions

Waste is considered as a source for producing energy in a sustainable manner. In this light, sustainable activities have received an increasing interest among waste management organizations in the city to improve their practices in the waste chain and develop sustainable waste management strategies. While energy justice challenges i.e. climate change, energy poverty, and energy security are distributed throughout the waste chain, local authorities in the city must carefully choose the most suitable technology. Unsuitable selection of the technology can be detrimental to the society. Therefore, there is a need to identify that some technologies may exacerbate these. Several studies have focused on waste-to-energy

(WTE) processes in the waste chain. The researchers have discussed various effective and efficient criteria in terms of both socioeconomic perspectives and environmental sustainability that the parties should use to evaluate WTE technologies. Nevertheless the lack of a model to assess these technologies based on energy justice criteria is strongly felt. Energy justice criteria can support the parties in decision making, monitoring and judging specific policies in the context of WTE production to achieve a balance between energy trilemma issues in a sustainable manner. In this study, all the alternative waste-to-energy production technologies was assessed using an integrated multi-criteria decision-making model. The model consists of fuzzy DEMATEL method, the analytic network process (ANP) and the simple additive weighting (SAW) approach, taking into account energy justice criteria. The DEMATEL and ANP were used to determine the importance weight of the technologies selection criteria in a fuzzy environment. The SAW method was used to select the most suitable waste-to-energy production technology. The results indicated that the main technologies of the research ranked as follows respectively: Anaerobic digestion, Gasification, Pyrolysis, and Incineration. Energy justice criteria for a sustainable waste management approach are defined in this research study. It is possible to create, implement, and evaluate energy justice based organizational strategies. Finding the correct balance between conflict demands of the climate change, energy poverty and energy security within the chain compatible to local limitations is the main strategy. These organizational strategies enable the chain to achieve its long-term and short-term objectives. For future studies in this area, appropriate methods for measuring the performance rate of these strategies are needed. There are studies that can help the researchers in this field (Sobhanallahi et al., 2016a, 2016b).

Accounting for the regional and global level of the selection problem in the waste chain, suitable models for handling it are also needed for future studies. These models are combined with optimal choices of equipment types and designs, maintenance scheduling of them, rewards-driven systems for waste management, location selection models for WTE power plants, survival analysis in waste supply chain (Shafipour and Fetanat, 2016) and so on. Examples of steps like these can be found in (Duan et al., 2018; Gharaei et al., 2015; Stehlík, 2011, 2009a; 2009b; Ucekaj et al., 2010).

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References

Abbasi, T., Tauseef, S.M., Abbasi, S.A., 2012. Anaerobic digestion for global warming control and energy generation—an overview. Renew. Sustain. Energy Rev. 16, 3228–3242.
Abbott, J., 2003. Environmental and health risks associated with the use of processed incinerator bottom ash in road construction. A Rep. Prod. BREWEB, AEA Technol. Environ.
Achillas, C., Vlachokostas, C., Moussiopoulos, N., Banias, G., Kafetzopoulos, G., Karagiannidis, A., 2011. Social acceptance for the development of a waste-to-energy plant in an urban area. Resour. Conserv. Recycl. 55, 857–863.
Appels, L., Baeyens, J., Degrève, J., Dewil, R., 2008. Principles and potential of the anaerobic digestion of waste-activated sludge. Prog. Energy Combust. Sci. 34, 755–781.
Asgharpour, M., 2011. Multiple Criteria Decision Making, ninth ed. Tehran University Press (In Persian).
Awasthi, A., Omrani, H., 2019. A goal-oriented approach based on fuzzy axiomatic design for sustainable mobility project selection. Int. J. Syst. Sci. Oper. Logist. 6, 86–98.
Ayodele, T.R., Ogunjuyigbe, A.S.O., Alao, M.A., 2017. Life cycle assessment of waste-to-energy (WtE) technologies for electricity generation using municipal solid waste in Nigeria. Appl. Energy 201, 200–218.
BP, 2017. Energy Outlook. BP.
Brunner, P.H., Rechberger, H., 2015. Waste to energy—key element for sustainable waste management. Waste Manag. 37, 3–12.
Büyüközkan, G., Çifçi, G., 2012. A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. Expert Syst. Appl. 39, 3000–3011.
Cheng, H., Hu, Y., 2010. Municipal solid waste (MSW) as a renewable source of energy: current and future practices in China. Bioresour. Technol. 101, 3816–3824.
Cucchiella, F., D'Adamo, I., Gastaldi, M., 2017. Sustainable waste management: waste to energy plant as an alternative to landfill. Energy Convers. Manag. 131, 18–31.
Cucchiella, F., D'Adamo, I., Gastaldi, M., 2014. Strategic municipal solid waste management: a quantitative model for Italian regions. Energy Convers. Manag. 77, 709–720.
Diaz-Barriga-Fernandez, A.D., Santibañez-Aguilar, J.E., Radwan, N., Nápoles-Rivera, F., El-Halwagi, M.M., Ponce-Ortega, J.M., 2017. Strategic planning for managing municipal solid wastes with consideration of multiple stakeholders. ACS Sustain. Chem. Eng. 5, 10744–10762.
Duan, C., Deng, C., Gharaei, A., Wu, J., Wang, B., 2018. Selective maintenance scheduling under stochastic maintenance quality with multiple maintenance actions. Int. J. Prod. Res. 1–19.
Ekşioğlu, S.D., Acharya, A., Leightley, L.E., Arora, S., 2009. Analyzing the design and management of biomass-to-biorefinery supply chain. Comput. Ind. Eng. 57, 1342–1352.
Fetanat, A., Khorasaninejad, E., 2015. A novel hybrid MCDM approach for offshore wind farm site selection: a case study of Iran. Ocean Coast. Manag. 109, 17–28.
Fetanat, A., Shafipour, G., Mohtasebi, S.-M., 2019. Measuring public acceptance of climate-friendly technologies based on creativity and cognitive approaches: practical guidelines for reforming risky energy policies in Iran. Renew. Energy 134, 1248–1261.
Gharaei, A., Hoseini Shekarabi, S.A., Karimi, M., 2019a. Modelling and optimal lot-sizing of the replenishments in constrained, multi-product and bi-objective EPQ models with defective products: generalised Cross Decomposition. Int. J. Syst. Sci. Oper. Logist. 1–13.
Gharaei, A., Karimi, M., Hoseini Shekarabi, S.A., 2019b. Joint economic lot-sizing in multi-product multi-level integrated supply chains: generalized benders decomposition. Int. J. Syst. Sci. Oper. Logist. 1–17.
Gharaei, A., Karimi, M., Shekarabi, S.A.H., 2019c. An integrated multi-product, multi-buyer supply chain under penalty, green, and quality control polices and a vendor managed inventory with consignment stock agreement: the outer approximation with equality relaxation and augmented penalty algorithm. Appl. Math. Model. 69, 223–254.
Gharaei, A., Naderi, B., Mohammadi, M., 2015. Optimization of rewards in single machine scheduling in the rewards-driven systems. Manag. Sci. Lett. 5, 629–638.
Heffron, R.J., McCauley, D., 2017. The concept of energy justice across the disciplines. Energy Policy 105, 658–667.
Heffron, R.J., McCauley, D., Sovacool, B.K., 2015. Resolving society's energy trilemma through the Energy Justice Metric. Energy Policy 87, 168–176.
Hoseini Shekarabi, S.A., Gharaei, A., Karimi, M., 2018. Modelling and optimal lot-sizing of integrated multi-level multi-wholesaler supply chains under the shortage and limited warehouse space: generalised outer approximation. Int. J. Syst. Sci. Oper. Logist. 1–21.
Iakovou, E., Karagiannidis, A., Vlachos, D., Toka, A., Malamakis, A., 2010. Waste biomass-to-energy supply chain management: a critical synthesis. Waste Manag. 30, 1860–1870.
IEA, 2016. World Energy Statistics 2016. Paris.
Jones, B.R., Sovacool, B.K., Sidortsov, R.V., 2015. Making the ethical and philosophical case for "energy justice. Environ. Ethics 37, 145–168.
Kalogirou, E.N., 2017. Waste-to-Energy Technologies and Global Applications. CRC Press.
Kalyani, K.A., Pandey, K.K., 2014. Waste to energy status in India: a short review. Renew. Sustain. Energy Rev. 31, 113–120.
Kern, F., Smith, A., 2008. Restructuring energy systems for sustainability? Energy transition policy in The Netherlands. Energy Policy 36, 4093–4103.
Khorasaninejad, E., Fetanat, A., Hajabdollahi, H., 2016. Prime mover selection in thermal power plant integrated with organic Rankine cycle for waste heat recovery using a novel multi criteria decision making approach. Appl. Therm. Eng. 102, 1262–1279.
Lee, A.H.I., Hung, M.-C., Kang, H.-Y., Pearn, W.L., 2012. A wind turbine evaluation model under a multi-criteria decision making environment. Energy Convers. Manag. 64, 289–300.
Lin, C.-J., Wu, W.-W., 2008. A causal analytical method for group decision-making under fuzzy environment. Expert Syst. Appl. 34, 205–213.
Lombardi, L., Carnevale, E., Corti, A., 2015. A review of technologies and performances of thermal treatment systems for energy recovery from waste. Waste Manag. 37, 26–44.
Malkow, T., 2004. Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. Waste Manag. 24, 53–79.
Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Pol. 41, 955–967.
Markowitz, E.M., Shariff, A.F., 2012. Climate change and moral judgement. Nat. Clim. Chang. 2, 243.
McCauley, D., 2017. Energy Justice: Re-balancing the Trilemma of Security, Poverty and Climate Change. Springer.
Menikpura, S.N.M., Sang-Arun, J., Bengtsson, M., 2016. Assessment of environmental

and economic performance of Waste-to-Energy facilities in Thai cities. Renew. Energy 86, 576–584.
Mohammadi, M., Harjunkoski, I., Mikkola, S., Jämsä-Jounela, S.-L., 2018. Optimal planning of a waste management supply chain. In: Computer Aided Chemical Engineering. Elsevier, pp. 1609–1614.
Ng, W.P.Q., Lam, H.L., Varbanov, P.S., Klemeš, J.J., 2014. Waste-to-energy (WTE) network synthesis for municipal solid waste (MSW). Energy Convers. Manag. 85, 866–874.
Nixon, J.D., Dey, P.K., Ghosh, S.K., Davies, P.A., 2013. Evaluation of options for energy recovery from municipal solid waste in India using the hierarchical analytical network process. Energy 59, 215–223.
Nizami, A.S., Ouda, O.K.M., Rehan, M., El-Maghraby, A.M.O., Gardy, J., Hassanpour, A., Kumar, S., Ismail, I.M.I., 2016. The potential of Saudi Arabian natural zeolites in energy recovery technologies. Energy 108, 162–171.
Nizami, A.S., Shahzad, K., Rehan, M., Ouda, O.K.M., Khan, M.Z., Ismail, I.M.I., Almeelbi, T., Basahi, J.M., Demirbas, A., 2017. Developing waste biorefinery in Makkah: a way forward to convert urban waste into renewable energy. Appl. Energy 186, 189–196.
Quadrelli, R., Peterson, S., 2007. The energy–climate challenge: recent trends in CO2 emissions from fuel combustion. Energy Policy 35, 5938–5952.
Rabbani, M., Foroozesh, N., Mousavi, S.M., Farrokhi-Asl, H., 2017. Sustainable supplier selection by a new decision model based on interval-valued fuzzy sets and possibilistic statistical reference point systems under uncertainty. Int. J. Syst. Sci. Oper. Logist. 1–17.
Rahman, S.M.S., Azeem, A., Ahammed, F., 2017. Selection of an appropriate waste-to-energy conversion technology for Dhaka City, Bangladesh. Int. J. Sustain. Eng. 10, 99–104.
Ren, X., Che, Y., Yang, K., Tao, Y., 2016. Risk perception and public acceptance toward a highly protested Waste-to-Energy facility. Waste Manag. 48, 528–539.
Santibañez-Aguilar, J.E., Ponce-Ortega, J.M., González-Campos, J.B., Serna-González, M., El-Halwagi, M.M., 2013. Optimal planning for the sustainable utilization of municipal solid waste. Waste Manag. 33, 2607–2622.
Santibañez-Aguilar, J.E., Martinez-Gomez, J., Ponce-Ortega, J.M., Nápoles-Rivera, F., Serna-González, M., González-Campos, J.B., El-Halwagi, M.M., 2015. Optimal planning for the reuse of municipal solid waste considering economic, environmental, and safety objectives. AIChE J. 61, 1881–1899.
Sayyadi, R., Awasthi, A., 2018. An integrated approach based on system dynamics and ANP for evaluating sustainable transportation policies. Int. J. Syst. Sci. Oper. Logist. 1–10.
Shafipour, G., Fetanat, A., 2016. Survival analysis in supply chains using statistical flowgraph models: predicting time to supply chain disruption. Commun. Stat. Methods 45, 6183–6208.
Singh, R.P., Tyagi, V.V., Allen, T., Ibrahim, M.H., Kothari, R., 2011. An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario. Renew. Sustain. Energy Rev. 15, 4797–4808.
Sobhanallahi, M.A., Gharaei, A., Pilbala, M., 2016a. Provide a new method to determine effectiveness or performance rate of organization strategies based on Freeman model and using improved dimensional analysis method. In: Industrial Engineering (ICIE), 2016 12th International Conference on. IEEE, pp. 125–133.
Sobhanallahi, M.A., Gharaei, A., Pilbala, M., 2016b. Provide a practical approach for measuring the performance rate of organizational strategies. In: Industrial Engineering (ICIE), 2016 12th International Conference on. IEEE, pp. 115–124.
Soltani, A., Sadiq, R., Hewage, K., 2016. Selecting sustainable waste-to-energy technologies for municipal solid waste treatment: a game theory approach for group decision-making. J. Clean. Prod. 113, 388–399.
Sovacool, B., 2013. Energy and Ethics: Justice and the Global Energy Challenge. Springer.
Sovacool, B.K., Burke, M., Baker, L., Kotikalapudi, C.K., Wlokas, H., 2017. New frontiers and conceptual frameworks for energy justice. Energy Policy 105, 677–691.
Sovacool, B.K., Dworkin, M.H., 2015. Energy justice: conceptual insights and practical applications. Appl. Energy 142, 435–444.
Sovacool, B.K., Dworkin, M.H., 2014. Global Energy Justice. Cambridge University Press.
Sovacool, B.K., Heffron, R.J., McCauley, D., Goldthau, A., 2016. Energy decisions reframed as justice and ethical concerns. Nat. Energy 1, 16024.
Statistical Review of World Energy. Energy economics | BP [WWW Document], n.d. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html. (Accessed 9 October 2017).
Stehlík, P., 2011. Conventional versus specific types of heat exchangers in the case of polluted flue gas as the process fluid–A review. Appl. Therm. Eng. 31, 1–13.
Stehlík, P., 2009a. Contribution to advances in waste-to-energy technologies. J. Clean. Prod. 17, 919–931.
Stehlík, P., 2009b. Efficient waste processing and waste to energy: challenge for the future. Clean Technol. Environ. Policy 11, 7–9.
Tehran Waste Management Organization, 2018 [WWW Document]. http://pasmand.tehran.ir/Default.aspx?tabid=199. (Accessed 20 January 2019).
Tzeng, G.-H., Chiang, C.-H., Li, C.-W., 2007. Evaluating intertwined effects in e-learning programs: a novel hybrid MCDM model based on factor analysis and DEMATEL. Expert Syst. Appl. 32, 1028–1044.
Ucekaj, V., Šarlej, M., Puchýř, R., Oral, J., Stehlík, P., 2010. Efficient and environmentally friendly energy systems for microregions. Clean Technol. Environ. Policy 12, 671–683.
Wang, Y.-J., 2015. A fuzzy multi-criteria decision-making model based on simple additive weighting method and relative preference relation. Appl. Soft Comput. 30, 412–420.
Wang, Z., Ren, J., Goodsite, M.E., Xu, G., 2018. Waste-to-energy, municipal solid waste treatment, and best available technology: comprehensive evaluation by an interval-valued fuzzy multi-criteria decision making method. J. Clean. Prod. 172, 887–899.
Wilkinson, P., Smith, K.R., Joffe, M., Haines, A., 2007. A global perspective on energy: health effects and injustices. Lancet 370, 965–978.
Wu, W.-W., 2012. Segmenting critical factors for successful knowledge management implementation using the fuzzy DEMATEL method. Appl. Soft Comput. 12, 527–535.
Zhang, Y., Huang, G.H., He, L., 2014. A multi-echelon supply chain model for municipal solid waste management system. Waste Manag. 34, 553–561.
Zhang, Y.M., Huang, G.H., He, L., 2011. An inexact reverse logistics model for municipal solid waste management systems. J. Environ. Manag. 92, 522–530.
Zhao, X., Jiang, G., Li, A., Wang, L., 2016. Economic analysis of waste-to-energy industry in China. Waste Manag. 48, 604–618.